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CERTIFICATION

I, Harumasa ISHIZAKI of FUSOH PATENT FIRM, Rindo Building, 5F, 37, Kanda-Higashimatsushita-cho, Chiyoda-ku, Tokyo, 101 Japan, hereby certify that I am the translator of the accompanying certified official copy of the patent application No. JP 2000-230553 for a patent filed in Japan on July 31, 2000 and certify that the following is a true and correct translation to the best of my knowledge and belief.

Dated this 21st day of October 2004

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This is to certify that the annexed is a true copy of the following application as filed with this Office.

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[TITLE OF THE INVENTION] SEMICONDUCTOR LASER DEVICE AND METHOD OF MANUFACTURING THE SAME

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[Title of the Invention] SEMICONDUCTOR LASER DEVICE AND METHOD OF MANUFACTURING THE SAME

[Claims]

[Claim 1] A semiconductor laser device comprising, on a GaAs substrate, an active layer structure for generating light, a cladding layer for confining the light therein and a resonating structure for converting the generated light into laser light, wherein:

said active layer is formed in a single quantum well (SQW) structure or multiple quantum well (MQW) structure having a high-strained $Ga_xIn_{1-x}As_{1-y}Sb_y$ well layer (wherein $0.003 \leq y \leq 0.008$)

[Claim 2] A semiconductor laser device comprising, on a GaAs substrate, an active layer structure for generating light, a cladding layer for confining the light therein and a resonating structure for converting the generated light into laser light, wherein:

said active layer is formed in a single quantum well (SQW) structure or multiple quantum well (MQW) structure having a high-strained $Ga_xIn_{1-x}As_{1-y1-y2}N_{y1}Sb_{y2}$ well layer (wherein $y1 < 0.03$, $0.002 \leq y2 \leq 0.025$).

[Claim 3] A method of manufacturing a semiconductor laser device including an active layer in a single quantum well (SQW) structure or multiple quantum well (MQW) structure having a high-strained $Ga_xIn_{1-x}As_{1-y}Sb_y$ well layer (wherein $0.003 \leq y \leq 0.008$), comprising the step of epitaxially growing said semiconductor laser device by using a molecular beam epitaxial process.

[Claim 4] A method of manufacturing a semiconductor laser comprising:

an active layer is formed in a single quantum well (SQW) structure or multiple quantum well (MQW) structure having a high-strained $Ga_xIn_{1-x}As_{1-y1-y2}N_{y1}Sb_{y2}$ well layer (wherein $y1 < 0.03$, $0.002 \leq y2 \leq 0.025$), comprising the step of epitaxially growing said semiconductor laser device by using a molecular beam epitaxial process.

[Detailed Description of the Invention]
[0001]
[Field of the Invention]

The present invention relates to a semiconductor laser device, more specifically, a semiconductor laser device having a lower threshold current, and a superior temperature characteristic and operating at a wavelength primarily between 0.9μm and 1.65μm, in particular, a long-wavelength-band semiconductor laser device operating at a wavelength between 1.2μm and 1.3μm

[0002]
[Prior Art]

Semiconductor laser devices operating at a wavelength band between 1.2 μm and 1.3 μm now attract larger attention for use as light sources in devices for optical communication subscriber lines.
Although a GaInAsP-family semiconductor laser device formed on an InP substrate is conventionally developed as a semiconductor laser device having an emission wavelength of 1.3 μm band, it has been a problem that the semiconductor materials used in the GaInAsP laser device has a poor characteristic temperature of the threshold current as low as 50K to 70K.

In order to install a semiconductor laser device in each of households as a light source, it is desired that the semiconductor laser module have a longer wavelength band and a superior temperature characteristic without using a cooling element, and also can be manufactured at a lower cost.

[0003]

Thus, a variety of semiconductor laser devices having improved temperature characteristics and longer emission wavelengths have been developed. As one of examples, it is reported [1] that a resonating structure using GaInNAs as an active layer having a wavelength band between 1.25μm and 1.3μm is formed on the GaAs substrate, to result in the rise of a temperature characteristic up to as high as about 180K. It

was experimentally assured that it achieved a higher temperature characteristic around 130K to 270K.

[1] M. Kondow et al. Jpn.J.Appl.Phys., vol.35(1996)", pp.1273-1275

[0004]

Moreover, it is also reported [2] that a characteristic temperature as high as around 140K-170K was realized by using a high-strained GaInAs semiconductor laser device operating at an emission wavelength band of 1.2 μm. In addition, since the commercial single mode (SM) optical fiber has a cutoff wavelength at 1.2 μm, the semiconductor laser device is expected for use as a light source in a local area network (LAN).

[2] F.Koyama et al., in IEEE Photon. Technol. Lett., vol.12(2000) pp.125-127

[0005]

With reference to Fig. 3, a conventional high-strained GaInAs semiconductor laser device having an emission wavelength of 1.2 μm is explained. Fig. 3 is a sectional view of the epitaxial structure of a conventional high-strained GaInAs semiconductor laser device having an emission wavelength of 1.2 μm.

The semiconductor laser device 40 includes a multi-layer structure formed on a plane 42 of an n-GaAs (100) substrate having films consecutively formed thereon an n-GaAs buffer layer 44 having a film thickness of 0.2 μm, an n-InGaP cladding layer 46 having a film thickness of 1.5 μm, a GaAs optical confinement layer 48 having a film thickness of 0.13 μm, a GaInAs active layer 50, a GaAs optical confinement layer 52 having a thickness of 0.13 μm, a p-InGaP cladding layer 54 having a film thickness of 1.5 μm, and a p-GaAs contact layer 56 having a film thickness of 0.35 μm.

[0006]

[Problems to be solved by the Invention]

In the conventional semiconductor laser device, an amount of compressive strain as high as 2.8% is used for the active layer, which necessitates a smaller critical thickness around 4 nm for avoiding a three-dimensional growth. This makes it difficult to achieve an emission wavelength larger than 1.12 μm by using practical process conditions. In particular, it is difficult to use a molecular beam epitaxial (MBE) process having a larger migration length. The term, "high strain" as used herein means the degree of strain as high as or above 1.5%.

[0007]

In a conventional GaInNAs semiconductor laser device, in order to realize a low threshold current in a wavelength band of 1.3 μm, nitrogen (N) is generally added at about 0.6% in atomic ratio relative to the V-group elements. This device, however, suffers from the higher amount of strain and from poor mixing capability of the constituent element, nitrogen, into the V-group elements due to nitrogen having a smaller radius of atoms. This device thus involves a three-dimensional growth and a large number of crystal defects, which degrades the optical quality for the crystal structure.

[0008]

Concerning the above problems, it is an object of the present invention to provide a semiconductor laser device having a lower threshold current, and also a semiconductor laser device having a superior temperature characteristic and a long wavelength by improving optical and crystallographic quality of high-strain GaInAs group, and GaInAsN group semiconductor layer.

[0009]

In general, there are methods to eptaxially grow a semiconductor layer having a high strain by making lower temperature for growth, higher atomic ratio of V/III group ratio, higher growth rate, and using a surfactant in order.

The technique using the surfactant [3] is such that elements having a property of higher segregation feasibility, such as Sb, Te and Sn, are

used in a MBE or MOCVD for reducing the surface energy and the surface diffusion length to thereby suppress the three-dimensional growth.

[3] M.Copel et al., in Phys.Rev.Lett.vol.63(1989) pp.632-635.

In the ordinary growth technique using the surfactant, the growth step is stopped or interrupted to dispose the surfactant on the underlying layer in an amount of 1 ML or less before growing the high-strained layer. Subsequently, the high-strained layer is grown. During the growth of the high-strained layer, the surfactant is not added, whereby the surfactant is segregated at the surface of the high-strained layer without incorporating into the high-strained layer.

[0010]

The present inventor noticed the effectiveness of addition of Sb in a minute amount of about 0.2%to 3.5% with respect to the amount of V-group elements together with addition of a Group-III element during the growth of the high strained layer, without disposing the surfactant on the underlying layer before growing the high-strained layer.

More specifically, a GalnAsSb layer is formed in a 1.2-μm-waveband GaInAs semiconductor laser device, whereas a GaInNAsSb layer is formed in a 1.3-μm-waveband GaInNAs semiconductor laser device. The experiments as detailed below and conducted by the inventor revealed the superiority of this technique to the conventional technique.

[0011]

First experiments

In the first experiments, Sb is added in a $GaIn_{0.39}As/GaAs$ single quantum well (SQW) active layer, to thereby manufacture a 1.2-μm-waveband semiconductor laser device.

The test layer structure 60 shown in Fig. 4, the n-GaAs (100) substrate surface overlying thereon using MBE method, consecutively disposed a 0.2-μm-thick n-GaAs buffer layer 64 ($n=2x10^{17}cm^{-3}$), a 0.25 μm-thick $n\text{-}In_{0.484}Ga_{0.516}P$ cladding layer 66 ($n=3x10^{17}cm^{-3}$), a 0.13-μm-thick GaAs optical confinement layer 68, a $GaIn_{0.39}AsSb/GaAs/InGaP$

SQW active layer structure 70, a 0.13-μm-thick GaAs optical confinement layer 72, and a 0.25-μm-thick p-$In_{0.484}Ga_{0.516}P$ cladding layer 74 ($p=5x10^{17}cm^{-3}$) were stacked consecutively on a (100) plane of a GaAs substrate 62 by using a MBE technique. The MBE technique may be replaced by a MOCVD technique.

[0012]

A $GaIn_{0.39}As$ SQW layer has a higher compressive strain as high as 2.8%. The design thickness of the SQW layer structure is set at 7.3 nm, wherein the relationship between the critical thickness and the In content is calculated to obtain 4 nm for the critical thickness based on the theory presented by J.W.Matthews and A.E.Blakeslee for the GaInAs/GaAs group.

In these experiments, Sb is added only to a $GaIn_{0.39}As$ SQW layer to form a GaInAsSb SQW layer. By changing the Sb flux (Torr) as a parameter, the photoluminescence (PL) dependency of the Sb flux was investigated. The results are shown in Fig. 5. The term flux (Torr) as used herein means the intensity of the molecular beam of Sb incident onto the substrate and evaluated in terms of the partial pressure at the surface of the substrate.

The growth conditions of the GaInAsSb layer in the experiments are as follows:

Chamber pressure--- 9.0×10^{-5}Torr,

Growth temperature--- 440 °C,

AsH_3 flux after cracking--- 8.5×10^{-5}Torr,

Growth rate of GaInAsSb SQW layer--- 2.1 μm/hour.

It is to be noted that AsH_3 and PH_3 are supplied after thermal decomposition or cracking at 1000°C, before they reach the substrate.

[0013]

Referring to Fig. 5, there is shown the dependencies of photoluminescence (PL) intensity and the PL wavelength on the Sb flux. It is understood from this drawing that Sb is effective in growth of a

high strained GaInAs layer and that the highest PL intensity is obtained by addition of Sb at about 2×10^{-7} Torr to 5×10^{-7} Torr.

[0014]

Second Experiments

In order to investigate the amount of incorporation of Sb into a GaInAs well layer, GaAsSb layers were epitaxially grown with different amounts of Sb flux, and the Sb contents (%) in the GaAsSb layers were measured.

The results is shown in Fig. 6. The growth rate, the AsH_3 flux, and the growth temperature in the second experiments were identical to the epitaxial growth conditions of the GaInAsSb well layer of the first experiments.

Sb was incorporated into the GaAs film in a linear relation with respect to the Sb flux up to 5×10^{-6}Torr, as shown in Fig. 6. Assuming that this Sb content is same as the Sb content in InGaAsSb, the quantum level of GaInAsSb is calculated. The results are shown in Fig. 5. It is also assumed that $\Delta Ec=0.7\Delta Eg$.
The PL wavelength indicated relatively good coincidence to the calculation up to a Sb flux of 2×10^{-6}Torr.

At 2×10^{-7} Torr where the PL intensity becomes the maximum (refer to first experiments), the composition of the GaInAsSb film resulted in $Ga_{0.61}In_{0.39}As_{0.9968}Sb_{0.0032}$, that means a minute amount of Sb was incorporated into the film. Thus, it is considered that Sb does not act as a surfactant, and that Sb is incorporated in the GaInAs film to act as a surfactant-like.

It is understood from Fig. 6 that, since the Sb content is 0.32% in terms of the atomic ratio relative to the V-group elements. Therefore, in view of Fig. 5, the Sb flux from 2×10^{-7} Torr to 5×10^{-7}Torr, or an amount of Sb addition from 0.3% to 0.8%, is considered to be optimum to obtain a high PL intensity.

[0015]

Third experiments

By changing the Sb flux (Torr) while fixing a specified condition, experiments for growing GaInNAsSb layers were conducted, and the results thus obtained are shown in Fig. 7. The structure for the third experiments is similar to the first experiments except that the SQW layer is implemented by $GaIn_{0.39}AsN_{0.0044}Sb$. The specified condition for growing the GaInAsNSb layer is as follows:

Chamber pressure--- 9.5×10^{-5}Torr;

Growth temperature--- 460 °C;

AsH_3 flux after cracking --- 8.5×10^{-5}Torr;

Growth rate of GaInAsNSb well layer -- 2.1 μm/hour

[0016]

The well layer had a compressive strain of 2.7% when the well layer had no Sb content ($GaIn_{0.39}AsN_{0.0044}$), and had a design thickness of 7.3 nm. In addition, the nitrogen radicals excited by a RF plasma source were used as the nitrogen source. In order to recover the excellent crystallography, after growth of a GaInNAsSb layer, a semi-insulating GaAs wafer is mounted on the GaInAsSb layer in a nitrogen ambient, in a planar contact (face-to-face) with the epitaxial layer side thereof, followed by an annealing step at a temperature of 650 °C for ten minutes. The semi-insulating GaAs wafer functions as a cap layer for preventing the escape of phosphorus atoms.

[0017]

Fig. 7 shows the Sb flux dependency of the PL intensity and the PL wavelength. It will be understood from Fig. 7 that a Sb flux of about 5×10^{-7} to 1×10^{-6} Torr is optimum for obtaining a higher PL intensity.

As described in connection with the second experiments for the growth of a GaAsSb layer, a Sb flux of 1×10^{-6} Torr provides a Sb content of 1.6% relative to the V-group elements, and the nitrogen content is calculated at 0.44% relative to the V-group elements based on the wavelength shift of the as-grown epitaxial layer occurring with the addition of nitrogen.

From the second and third experiments, it was confirmed that the optical property of the GaInNAs layer is improved by the addition of Sb at an amount of 0.8 to 1.6%.

[0018]

In addition, in order to increase the laser emission wavelength to 1.3μm, the nitrogen content should be increased to some extent, which necessitates increase of the Sb content. Although the optimum Sb content depends on the composition of the layer, a larger N content generally increases the optimum Sb content.

Nitrogen content is about 0.7% required for GaInAs well layer of 1.3μm-bandwidth semiconductor laser device which makes necessary Sb content between about 0.8% - 2.5%. The Sb content of 2.5% is determined considering nitrogen amount based on the above upper limit of 1.6%.

More specifically, the above description can be calculated as:

1.6% (Maximum optimum amount of Sb of third embodiment) × [0.7%(N amount required for 1.3μm wavelength)]/[0.44 (N amount of third embodiment)]=0.25%

On the other hand, for example, if 980nm-waveband semiconductor laser device having a low N content of GaInNAs well layer, N amount becomes smaller than 0.44% used in third experiments which makes Sb amount smaller between about 0.2% - 2%.

[0019]

In view of the above experiments and experimental results, optical quality can be significantly improved by adding Sb as a structural element to GaInAs layer between a range more than 0.3% and less than 0.8% relative to the V-group elements while GaInAs layer is growing for the high-strained GaInAs layer having light emission wavelength of 1.2μm, and adding Sb as a structural element to GaInNAs layer between a range more than 0.2% and less than 2.5% relative to the V-group elements while GaInNAs layer is growing. Here, crystallographic

quality becomes degraded if N content is increased, practical limitation of N content relative to V-group is therefore less than 3%.

[0020]

In order to achieve the above object, based on the above findings, a semiconductor laser device (hereafter first invention) according to the present invention comprising:

a GaAs substrate overlying thereon;

an active layer structure for generating light, a cladding layer for confining the light therein and a resonating structure for converting the generated light into laser light wherein:

said active layer is formed in a single quantum well (SQW) structure having a high-strained $Ga_xIn_{1-x}As_{1-y}Sb_y$ well layer (wherein $0.003 \leq 1-y \leq 0.008$)

[0021]

Also, a semiconductor laser device (hereafter second invention) according to the present invention comprising:

a GaAs substrate overlying thereon;

an active layer structure for generating light, a cladding layer for confining the light therein and a resonating structure for converting the generated light into laser light wherein:

said active layer is formed in a single quantum well (SQW) structure having a high-strained $Ga_xIn_{1-x}As_{1-y1-y2}N_{y1}Sb_{y2}$ well layer (wherein $y1 < 0.03$, $0.002 \leq y2 \leq 0.025$).

[0022]

Further, a method of manufacturing a semiconductor laser device by the first invention comprising:

an active layer in a single quantum well (SQW) structure having a high-strain $Ga_xIn_{1-x}As_{1-y}Sb_y$ well layer (wherein $0.003 \leq 1-y \leq 0.008$) wherein said semiconductor laser device is epitaxially grown by molecular beam epitaxial process.

Furtehr more, a method of manufacturing a semiconductor laser by the second invention comprising:

an active layer is formed in a single quantum well (SQW) structure having a high-strained $Ga_xIn_{1-x}As_{1-y1-y2}N_{y1}Sb_{y2}$ well layer (wherein $y1<0.03$, $0.002 \leq y2 \leq 0.025$) wherein said semiconductor laser device is epitaxially grown by molecular beam epitaxial process.

The above present invention can be applied to either one of light confinement structure having SCH structure or $Al_xGa_{1-x}As$ layer having GRIN (Graded Refractive Index)-SCH.

Also, concerning the waveguide structure, the present invention can be applied to either one of ridge waveguide semiconductor laser device, or buried hetero-structure (BH) semiconductor laser device.

Also, the present invention can be applied to semiconductor laser devices having wavelength of 980nm waveband, 1480nm waveband, or 1650nm waveband by adjusting the amount of N and Sb.

[0023]

[Embodiments]

Now, the present invention is more specifically described with reference to accompanying drawings based on embodiments.

Embodiment 1 of the semiconductor laser device

Referring to Fig. 1, a semiconductor laser device according to a first embodiment of the present invention is implemented as a 1.2-μm band GaInAsSb semiconductor laser device. Fig. 1 is a sectional view of the epitaxial structure of a semiconductor laser device according to a first embodiment of the present invention.

As Fig. 1 shows, the semiconductor laser device 10 includes an n-GaAs substrate 12 having a thickness of 100 μm and a main surface directed to (100) plane, a 0.5-μm-thick n-GaAs ($n=1\times10^{18}cm^{-3}$) buffer layer 14 having an n-type impurity concentration of, a 1.5-μm-thick n-$In_{0.49}Ga_{0.51}P$ ($n=1\times10^{18}cm^{-3}$) cladding layer 16, a 0.1-μm-thick GaAs optical confinement layer 18, a SQW active layer structure 20 including a GaInAsSb SQW layer, a 0.1-μm-thick GaAs optical confinement layer 22, a 1.5-μm-thick p-$In_{0.49}Ga_{0.51}P$ ($p=1\times10^{18}cm^{-3}$) cladding layer 24, and a 0.3-μm-thick p-GaAs ($p=3\times10^{19}cm^{-3}$) contact

layer 26, which are consecutively formed on the (100) plane of the GaAs substrate 12.

[0024]

The SQW active layer structure 20 includes a single well layer made of $Ga_{0.61}In_{0.39}As_{0.9968}Sb_{0.0032}$ having a compressive strain of 2.82%, and the thickness of the well layer is 7.3 nm.

The GaInAsSb well layer is grown under the following conditions in case of gas-source MBE growth:

Chamber pressure-- 9.0×10^{-5}Torr;

Growth temperature-- 460 °C;

AsH_3 flux after cracking-- 8.5×10^{-5} Torr;

Growth rate of GaInAsSb -- 2.1 μm/hour; and

Sb flux -- 2.0×10^{-7} Torr.

The above layers are grown by either a gas-source MBE technique, MBE technique, CBE technique, or MOCVD technique.

[0025]

Although not explicitly illustrated, the semiconductor laser device of the present embodiment is formed as a ridge waveguide semiconductor laser device by photo-lithography process and mesa-etching of the above layers to have an active layer width of 3 μm.

The semiconductor laser device also includes a p-side ohmic electrode made of metallic layers including Au-Zn or Ti/Pt/Au laminated films etc. on the contact layer 26, and an n-side ohmic electrode made of metallic layers including Au-Ge/Ni/Au laminated films.

The semiconductor laser device has a cavity length of 200 μm, and includes a high reflective (HR)-coat having a reflectance of 78% at the front facet and a HR-coat having a reflectance of 95% at the rear facet.

[0026]

A sample of the semiconductor laser device of the present embodiment was wire-bonded and measured its optical output with respect to injected current. The results of the measurements were such that the threshold current at 20 °C was 6 mA, the characteristic

temperature of the threshold current between 20 and 70 °C was 256K, and CW emission wavelength was 1.20 μm at a room temperature. In short, the sample had a threshold current which is lowest among the high-strained GaInAs semiconductor laser devices reported heretofore and a characteristic temperature, which is significantly higher than those of the conventional ones.

[0027]

Embodiment 2 of the semiconductor laser device

Referring to Fig. 2, a semiconductor laser device according to a second embodiment of the present invention is implemented as a GaInAsN semiconductor laser device having an emission wavelength of 1.25 to 1.3 μm band. Fig. 2 is a sectional view of the epitaxial structure of a semiconductor laser device according to a second embodiment.

The semiconductor laser device 30 of the present embodiment is similar to the first embodiment except that a SQW active layer structure 32 including a single GaInAsNSb well layer is used in the present embodiment instead of the GaInAsSb SQW structure 20 in the first embodiment.

The SQW active layer structure 32 includes a single $Ga_{0.61}In_{0.39}As_{0.9796}N_{0.0044}Sb_{0.016}$ well layer having a thickness of 7.3 nm.

[0028]

The GaInNAsSb well layer is grown under the following conditions:

Chamber pressure-- 9.0×10^{-5}Torr;

Growth temperature-- 460 °C;

AsH_3 flux after cracking-- 8.5×10^{-5} Torr;

Growth rate of GaInNAsSb -- 2.1 μm/hour; and

N_2 flux -- 2.0×10^{-6} Torr.

[0029]

A sample of the semiconductor laser device of the present embodiment was wire-bonded and measured its optical output with respect to injected current. The results of the measurements were such

that the threshold current at 20 °C was 10 mA, the characteristic temperature of the threshold current between 20 and 70 °C was 146K, and the CW emission wavelength was 1.26 μm at a room temperature. In short, the sample had a threshold current which is the lowest among the high-strained GaInNAs semiconductor laser devices reported heretofore and a characteristic temperature which is significantly higher than those of the conventional ones.

[0030]

Although the sample had a CW emission wavelength of 1.2 μm or 1.26 μm, a semiconductor laser device having 1.3 μm wavelength can be fabricated by fine-adjusting N content and Sb content in the embodiment.

In the embodiments 1 and 2, SQM structure is exemplified for description, multiple quantum well (MQM) structure may be used

The In content may be preferably in the range between 15% and 45% although the In content in the embodiments was exemplified at 39% in the embodiments 1 and 2.

[0031]

The lattice matched GaAs barrier layer used in the first or second embodiment, it may be GaInAsP layer, each of which may have a strain. The GaAs optical confinement layer having a SCH (Separate Confinement Heterostructure) configuration as used in the embodiments may be replaced by an $Al_xGa_{1-x}As$ layer having a GRIN (Graded Refractive Index)-SCH configuration. In addition, the cladding layer may be made of AlGaAs.

In the examples of the first and second embodiments, the ridge waveguide type semiconductor laser element is exemplified; buried hetro-structure (BH) stripe-type semiconductor laser element may be used.

In the examples of the first and second embodiments, the semiconductor laser devices had emission wavelengths of 1200 nm and 1250 to 1300 nm. The present invention can be applied to a semiconductor laser device having emission wavelengths of 980 nm,

1480 nm, 1550 nm, 1650 nm etc. by modifying the nitrogen content and the Sb content.

[0032]

[Effect of the Invention]

According to the present invention, optical characteristics of the well layer can be improved by adding Sb as a small structural element in either high-strained GaInAs well layer or high-strained GaInNAs well layer.

Accordingly, a semiconductor laser element having optical emission wavelength between 0.9μm – 1.65μm waveband, a low threshold current, and temperature characteristics suitable for Peltier effect-free application.

[Brief Description of the Drawings]

Fig. 1 is a sectional view of the epitaxial structure of a semiconductor laser device according to a first embodiment of the present invention.

Fig. 2 is a a sectional view of the epitaxial structure of a semiconductor laser device according to a second embodiment of the present invention.

Fig. 3 is a sectional view of the epitaxial structure of a conventional high-strained GaInAs semiconductor laser device having an emission wavelength of 1.2 μm.

Fig. 4 is a sectional view of a test piece of a sample multi-layer structure having epitaxial layer structure.

Fig. 5 is a graph showing test results for the dependency of the PL characteristics of a SQW structure on the amount of Sb flux, the SQW structure having GaInAsSb/GaAs/InGaP layers obtained by experiments.

Fig. 6 is a graph showing the relationship obtained by experiments between the amount of Sb flux and the Sb composition of GaAsSb.

Fig. 7 is a graph showing the test results for the dependency of the PL characteristic of a SQW structure on the amount of Sb flux, the SQW structure having GaInAsNSb/GaAs/InGaP layers.

[Description of Signs]

10 epitaxial structure of the semiconductor laser device of embodiment 1

12 n-GaAs (100) substrate surface

14 n-GaAs ($n=1x10^{18}cm^{-3}$) buffer layer having a film thickness of 0.5μm

16 $In_{0.49}Ga_{0.51}P$ ($n=1x10^{18}cm^{-3}$) cladding layer having a film thickness of 1.5μm.

18 GaAs light confinement layer having a film thickness of 0.1μm

20 $Ga_{0.61}In_{0.39}As_{0.9968}Sb_{0.0032}$ SQW single quantum well structure having a compressed strain of 2.82%

22 GaAs light confinement layer having film thickness of 0.1μm

24 p-$In_{0.49}Ga_{0.51}P$ ($p=1x10^{18}cm^{-3}$) cladding layer having a film thickness of 1.5μm

26 p-GaAs ($p=3x10^{19}cm^{-3}$) contact layer having a film thick ness of 0.3μm

30 epitaxial structure of the semiconductor laser device of embodiment 2

32 $Ga_{0.61}In_{0.39}As_{0.9796}N_{0.0044}Sb_{0.016}$ SQW single quantum well structure having a compressed strain of 2.81%

40 conventional epitaxial structure of high-strained GaInAs semiconductor laser device having a wavelength of 1.2μm

42 n-GaAs (100) substrate surface

44 n-GaAs buffer layer having a film thickness of 0.2μm

46 n-InGaP cladding layer having a film thickness of 1.5μm.

48 GaAs light confinement layer having a film thickness of 0.13μm

50 InGaP active layer

52 GaAs light confinement layer having film thickness of 0.13μm

54 p-InGaP cladding layer having a film thickness of 1.5μm

56 p-GaAs contact layer having a film thick ness of 0.35μm

60 test piece layer structure

62 n-GaAs (100) substrate surface

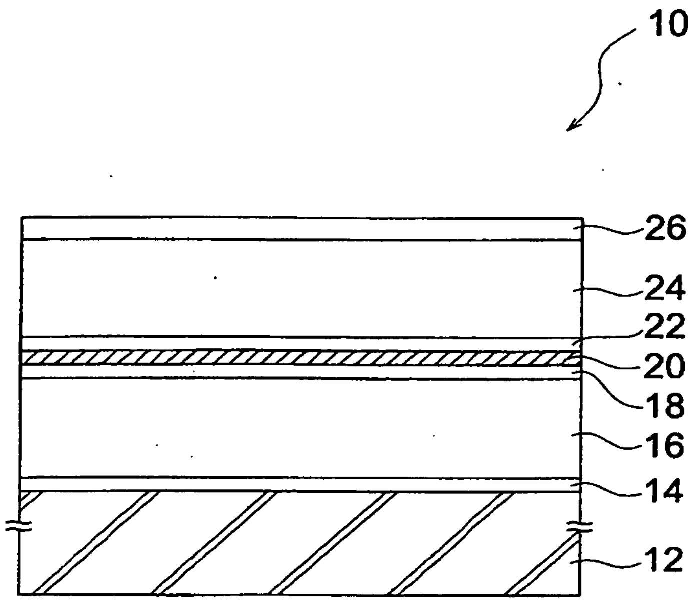
64 n-GaAs ($n=2x10^{17}cm^{-3}$) buffer layer having a film thickness of 0.2μm

66 n-$In_{0.47}Ga_{0.53}P$ ($n=3x10^{17}cm^{-3}$) cladding layer having a film thickness of 0.25μm.

68 GaAs light confinement layer having a film thickness of 0.13μm
70 $GaIn_{0.39}AsSb/GaAs/InGaP$ single quantum well structure
72 GaAs light confinement layer having a film thickness of 0.13μm
74 p-$In_{0.47}Ga_{0.53}P$ ($p=5\times10^{17}cm^{-3}$) cladding layer

[Name of Document] Drawings

[Fig. 1]



10 epitaxial structure of the semiconductor laser device of embodiment 1

12 n-GaAs (100) substrate surface

14 n-GaAs ($n=1x10^{18}cm^{-3}$) buffer layer having a film thickness of 0.5μm

16 $In_{0.49}Ga_{0.51}P$ ($n=1x10^{18}cm^{-3}$) cladding layer having a film thickness of 1.5μm.

18 GaAs light confinement layer having a film thickness of 0.1μm

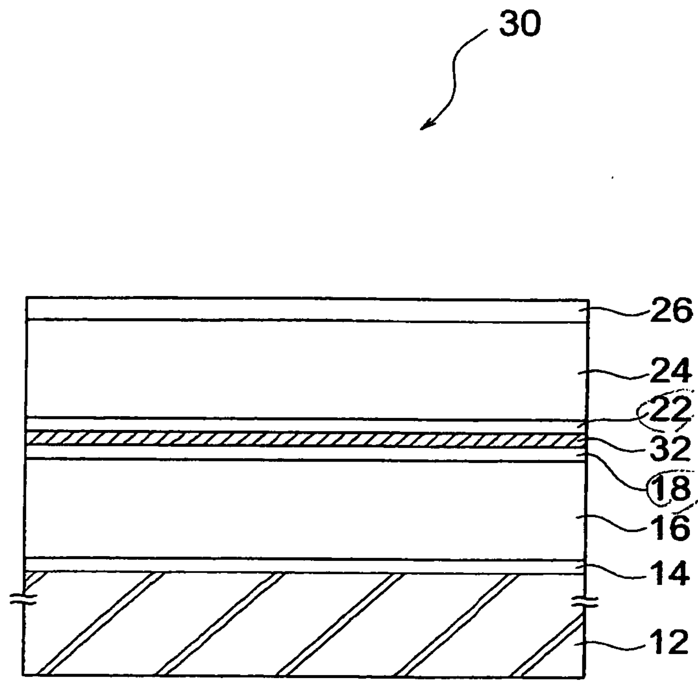
20 $Ga_{0.61}In_{0.39}As_{0.9968}Sb_{0.0032}$ SQW single quantum well structure having a compressed strain of 2.82%

22 GaAs light confinement layer having film thickness of 0.1μm

24 p-$In_{0.49}Ga_{0.51}P$ ($p=1x10^{18}cm^{-3}$) cladding layer having a film thickness of 1.5μm

26 p-GaAs ($p=3x10^{19}cm^{-3}$) contact layer having a film thick ness of 0.3μm

[Fig. 2]



30 epitaxial structure of the semiconductor laser device of embodiment 2

12 n-GaAs (100) substrate surface

14 n-GaAs ($n=1x10^{18}cm^{-3}$) buffer layer having a film thickness of 0.5μm

16 $In_{0.49}Ga_{0.51}P$ ($n=1x10^{18}cm^{-3}$) cladding layer having a film thickness of 1.5μm.

18 GaAs light confinement layer having a film thickness of 0.1μm

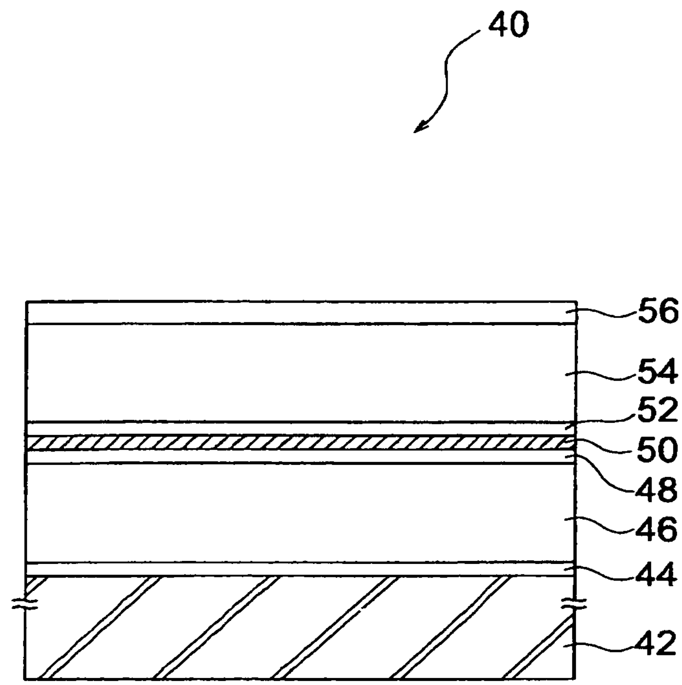
32 $Ga_{0.61}In_{0.39}As_{0.9796}N_{0.0044}Sb_{0.016}$ SQW single quantum well structure having a compressed strain of 2.81%

22 GaAs light confinement layer having film thickness of 0.1μm

24 p-$In_{0.49}Ga_{0.51}P$ ($p=1x10^{18}cm^{-3}$) cladding layer having a film thickness of 1.5μm

26 p-GaAs ($p=3x10^{19}cm^{-3}$) contact layer having a film thick ness of 0.3μm

[Fig. 3]



40 conventional epitaxial structure of high-strained GaInAs semiconductor laser device having a wavelength of 1.2μm

42 n-GaAs (100) substrate surface

44 n-GaAs buffer layer having a film thickness of 0.2μm

46 n-InGaP cladding layer having a film thickness of 1.5μm.

48 GaAs light confinement layer having a film thickness of 0.13μm

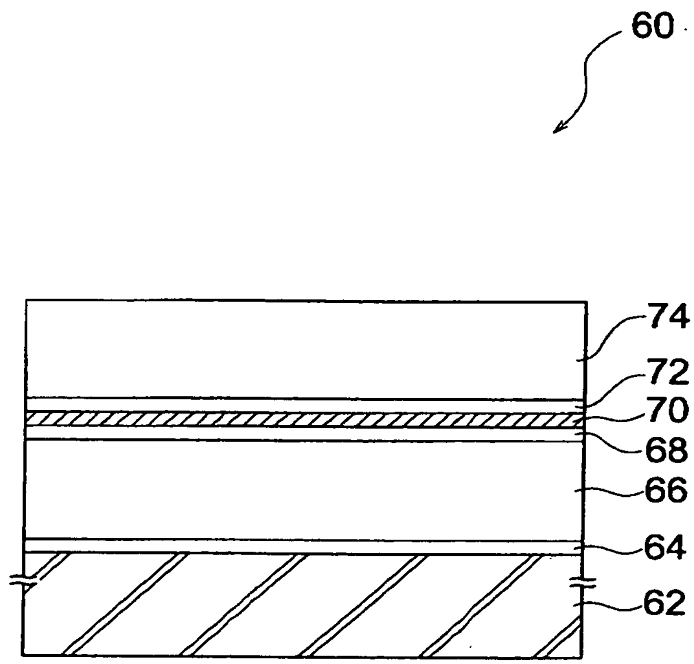
50 InGaP active layer

52 GaAs light confinement layer having film thickness of 0.13μm

54 p-InGaP cladding layer having a film thickness of 1.5μm

56 p-GaAs contact layer having a film thick ness of 0.35μm

[Fig. 4]



60 test piece layer structure

62 n-GaAs (100) substrate surface

64 n-GaAs ($n=2x10^{17}cm^{-3}$) buffer layer having a film thickness of 0.2μm

66 n-$In_{0.47}Ga_{0.53}P$ ($n=3x10^{17}cm^{-3}$) cladding layer having a film thickness of 0.25μm.

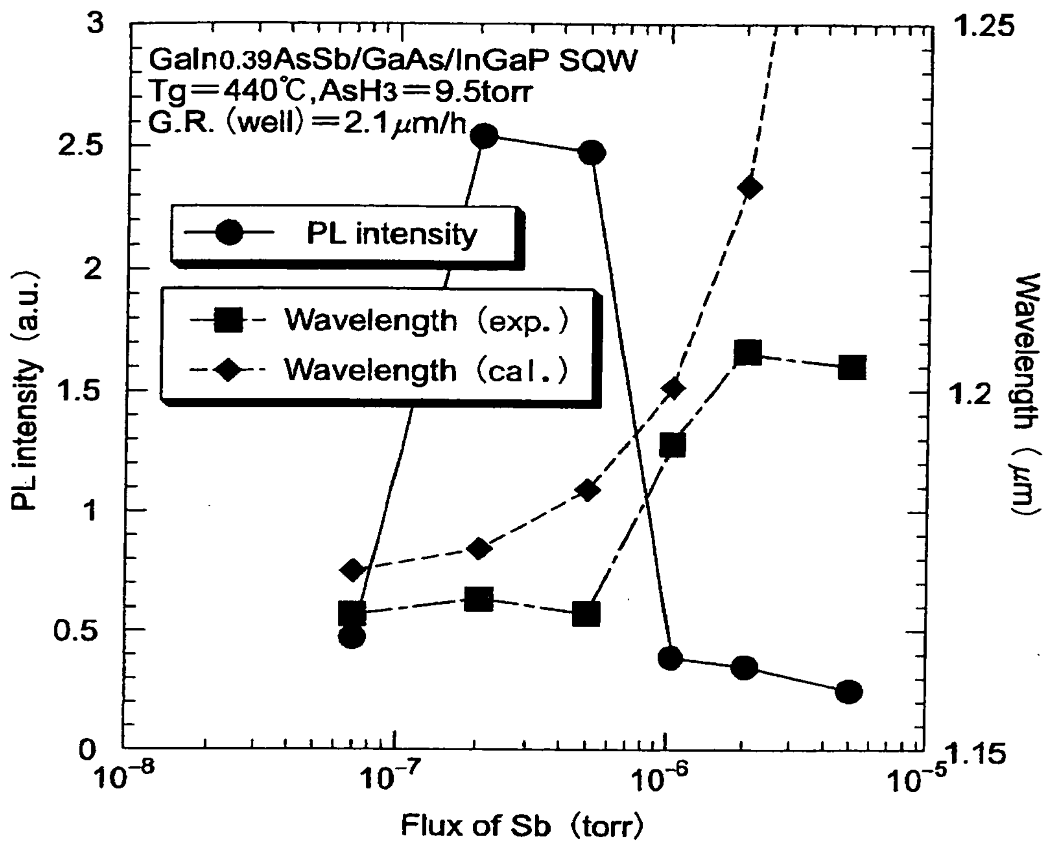
68 GaAs light confinement layer having a film thickness of 0.13μm

70 $GaIn_{0.39}AsSb$/GaAs/InGaP single quantum well structure

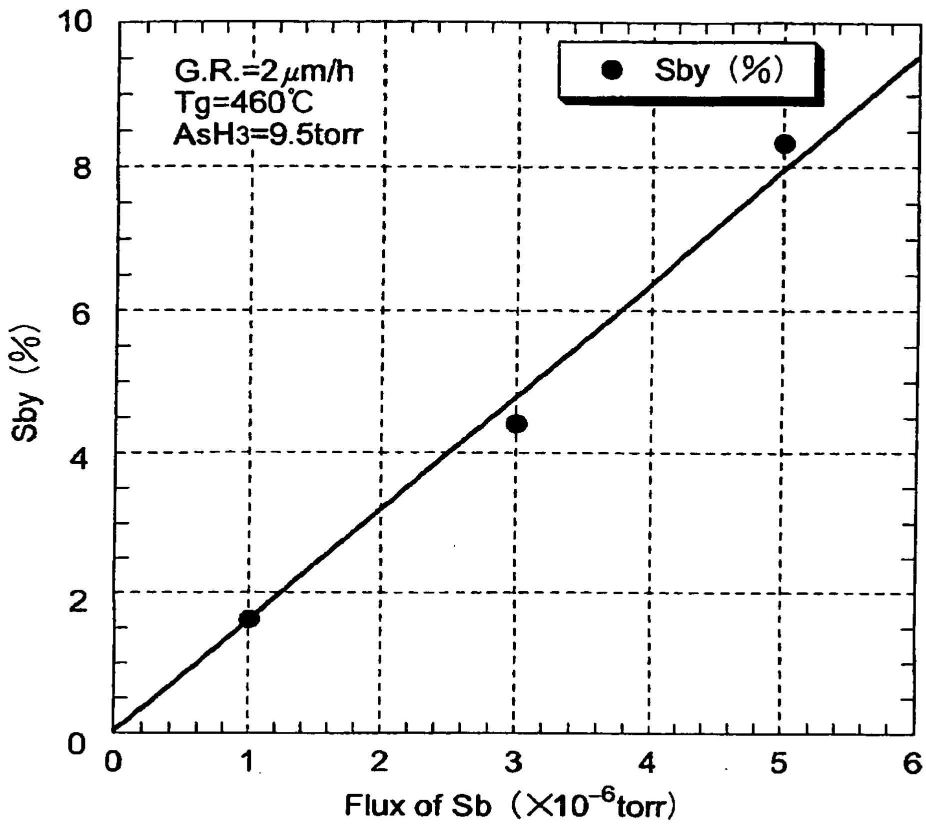
72 GaAs light confinement layer having a film thickness of 0.13μm

74 p-$In_{0.47}Ga_{0.53}P$ ($p=5x10^{17}cm^{-3}$) cladding layer

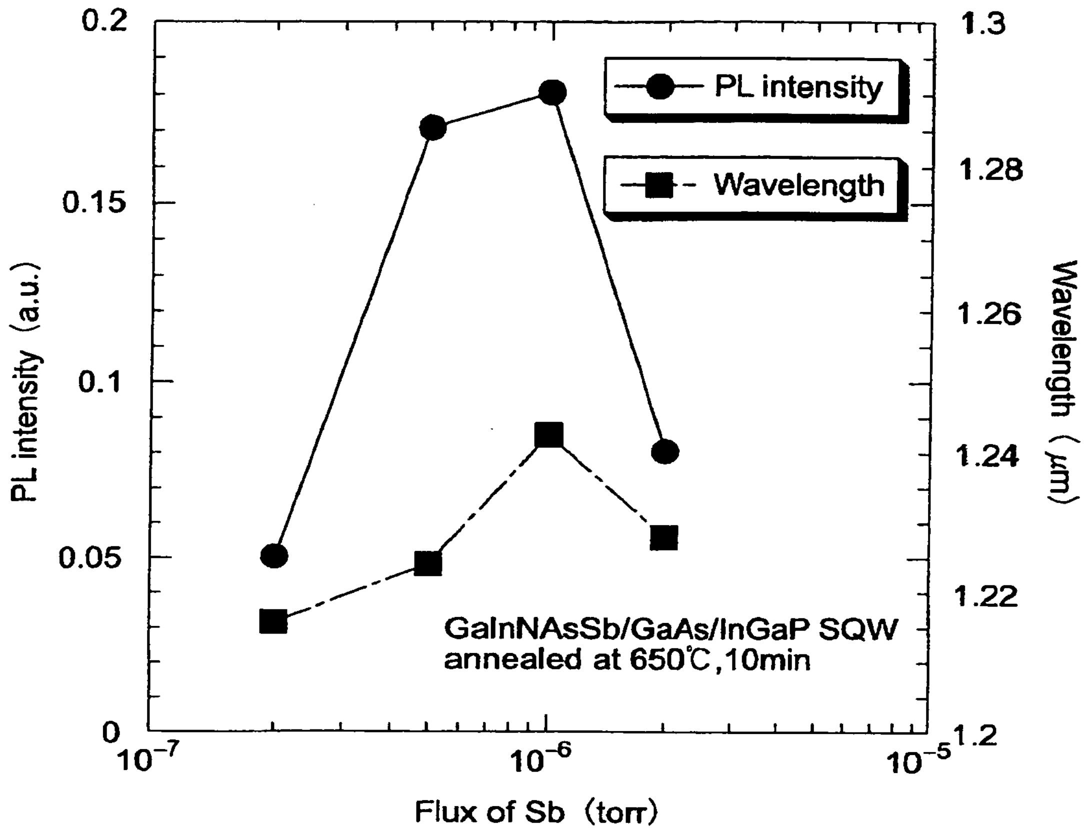
[Fig. 5]


GaIn0.39AsSb/GaAs/InGaP SQW
Tg=440℃,AsH3=9.5torr
G.R. (well)=2.1μm/h
PL intensity
Wavelength (exp.)
Wavelength (cal.)
PL intensity (a.u.)
Wavelength (μm)
Flux of Sb (torr)
3
2.5
2
1.5
1
0.5
0
1.25
1.2
1.15
10⁻⁸
10⁻⁷
10⁻⁶
10⁻⁵

[Fig. 6]


G.R.=2μm/h
Tg=460℃
AsH3=9.5torr
Sby (%)
10
8
6
4
2
0
0
1
2
3
4
5
6
Flux of Sb (×10-6torr)

[Fig. 7]


0.2
0.15
0.1
0.05
0
PL intensity (a.u.)
1.3
1.28
1.26
1.24
1.22
1.2
Wavelength (μm)
PL intensity
Wavelength
GaInNAsSb/GaAs/InGaP SQW
annealed at 650℃,10min
10^-7
10^-6
10^-5
Flux of Sb (torr)

[Name of Document] Abstract

[Abstract]

[Object] Provide a longer wavelength semiconductor laser device having a low threshold current, and high temperature characteristics.

[Means for solving the problem] The semiconductor laser device 10 of the present invention has SQW or MQW well structure having high-strained $Ga_xIn_{1-x}As_{1-y}Sb_y$ well layer (wherein $0.003 \leq y \leq 0.008$) as the active layer. The semiconductor laser device includes an n-GaAs (100) substrate has a main surface 12 overlying thereon, consecutively, a 0.5-μm-thick n-GaAs ($n=1\times10^{18}cm^{-3}$), buffer layer 14, n-$In_{0.49}Ga_{0.51}P$ ($n=1\times10^{18}cm^{-3}$) cladding layer 16, GaAs optical confinement layer 18, a SQW active layer structure 20 including a GaInAsSb SQW layer, GaAs optical confinement layer 22, p-$In_{0.49}Ga_{0.51}P$ ($p=1\times10^{18}cm^{-3}$) cladding layer 24, and p-GaAs ($p=3\times10^{19}cm^{-3}$) contact layer 26. The SQW active layer structure includes a single well layer made of $Ga_{0.61}In_{0.39}As_{0.9968}Sb_{0.0032}$ having a compressive strain of 2.82%, and GaAs optical confinement layers, and the thickness of the well layer is 7.3 nm.

[Selected Drawing] Fig. 1